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Technical Report ARAED-TR-96002

**METALLURGICAL ANALYSIS OF AN ALUMINUM SABOT FIRED
IN THE CANNON CALIBER ELECTROMAGNETIC GUN (CCEMG)**

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June 1996



US ARMY
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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operation and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE June 1996		3. REPORT TYPE AND DATES COVERED	
4. TITLE AND SUBTITLE METALLURGICAL ANALYSIS OF AN ALUMINUM SABOT FIRED IN THE CANNON CALIBER ELECTROMAGNETIC GUN (CEMG)				5. FUNDING NUMBERS	
6. AUTHOR(S) Stacey Clark Kerwien					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSES(S) ARDEC, AED Materials and aeroballistics Technology Division (AMSTA-AR-AET-M) Picatinny Arsenal, NJ 07806-5000				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(S) ARDEC, DOIM Information Research Center (AMSTA-AR-IMC) Picatinny Arsenal, NJ 07806-5000				10. SPONSORING/MONITORING AGENCY REPORT NUMBER Technical Report ARAED-TR-96002	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) An aluminum 7475 alloy sabot fired from the Cannon Caliber Electromagnetic Gun was metallurgically characterized. More melting was seen on the rear contact surface than the front, and bubbles due to high-temperature oxidation were observed. The hardness profile showed a decrease in hardness along the outer surfaces of the sabot. Cracks caused by overheating were found.					
14. SUBJECT TERMS Electromagnetic launch High temperature oxidation				15. NUMBER OF PAGES 17	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT SAR		

ACKNOWLEDGMENTS

The author would like to thank Dr. Karl Lukens, ARDEC and Dr. Paul Hasse, University of Texas for their assistance and technical guidance.

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OBJECTIVE

The objective was to metallurgically characterize the material degradation of an Al-7475 alloy sabot fired in the Cannon Caliber Electromagnetic Gun (CCEMG) from Launcher IIa during shot 11 (Sabot Design 38M-CP-9007/00-06R). Also, characterize debris taken from the launcher during commissioning shots.

BACKGROUND

Shot 11 was fired at the Army Research Laboratory (ARL), Aberdeen Proving Ground, Maryland on September 23, 1994 at a velocity of 618 ms and a charge voltage of 5 kV.

EXPERIMENTAL PROCEDURE

One of the two sabots fired during shot 11 was found at the ARL test range (fig. 1). The contact surfaces of the sabot were examined macroscopically with the SEM at low magnification to qualitatively determine the extent of melting. One of the sabot halves was mounted in epoxy and polished to perform hardness measurements [diamond pyramid hardness (DPH)], semi-quantitative chemistry using energy dispersive x-rays (EDAX), and conductivity measurements. Then, the specimen was etched to reveal the microstructure.

The launcher debris was analyzed using: EDAX--to determine elements present, wavelength dispersive spectroscopy (WDS)--to verify the presence or absence of carbon and oxygen, and x-ray diffraction (XRD)--to verify the alloys and compounds formed. Several large particles of the debris were mounted and polished to examine their microstructures.

RESULTS AND DISCUSSION

Overall Condition of Sabot

The rear contact surfaces of the sabot melted more and lost more material than the front contacts. This suggests that the rear contacts carried more current and/or had more intimate mechanical contact with the rails. The tips of all of the contact surfaces had melted off and were somewhat deformed.

A significant amount of melting was also seen in the tail region (or projectile stabilizer). Since the tail does not contact the rails, melting must be due to the extremely high temperature of the launcher atmosphere. The temperature of the launcher is high as a result of the high electrical currents and the pyrophoric nature of aluminum particles.

SEM of Melted Surfaces

Figure 2 shows an SEM photograph of the rear contact surface near the tip. Bubbles and cracks in the structure are a result of high temperature oxidation (HTO). This occurs when aluminum is heated to its solution temperature or beyond in an atmosphere that contains water. Atomic hydrogen from the water reacts with the aluminum surface and diffuses through the aluminum lattice. The hydrogen then recombines to form molecular hydrogen, which is what causes the bubbles to form.

Microstructural Changes in the Sabot Material

For purposes of comparison, a typical microstructure of forged Al-7475 is shown in figure 3. Here, elongated aluminum grains with insoluble particles and second phase particles of magnesium and silicon are seen.

Examination of the sabot microstructure focused on the rear contact surface since it had the highest degree of melting. Figure 4 shows an area of high temperature oxidation in the rear contact surface. Here the aluminum has bubbled, deformed, and resolidified--forming a different microstructure than is typical for Al-7475. In fact, the microstructure in figure 4 is similar to an electron beam welded Al-7475. A network of interdendritic aluminum, magnesium, and silicon compounds has replaced the elongated grains of aluminum.

Figure 5 shows the very tip of the rear contact. The temperature was so concentrated that the elongated grains of aluminum have separated along the grain boundaries. This effect is called over-aging.

Figure 6 is the microstructure of the area on the bottom side of the rear contact surface. Even though this side did not come in contact with the rails, it also melted, formed bubbles, and developed a microstructure similar to that in figure 4. The bubbles are caused by high temperature oxidation.

Figure 7 shows a crack that has formed at the root of the back fin. This crack is 350 μ long. To understand the mechanisms of the crack initiation and growth, the area was viewed at a higher magnification (fig. 8). As seen in figures 4 and 6, a section of this microstructure looks similar to an electron beam weld. Next to this microstructure,

where the cracks are located, is an area of over-aged aluminum. In this region, the heat was just enough to cause the magnesium and silicon in Al-7475 to diffuse out to the grain boundaries of the aluminum, substantially weakening the aluminum causing it to crack. These cracks were not formed from mechanical stress--they were formed from material changes brought on by the heat.

Hardness

The hardness of Al-7475 is supposed to be 170-175 DPH. The hardness of the aluminum sabot is lower than this because of exposure to intense heat in the launcher. Figure 9 shows the hardness values from selected regions of the sabot. Only the central body of the armature did not experience hardness degradation. Softening occurred along the contact surfaces, at the roots of the contact surfaces, and along the tail or penetrator stabilizer area. The lowest hardnesses were seen at the tips of the contact surfaces and at the roots.

Bulk Conductivity

The conductivity was measured to be 34% IACS, which is typical of Al-7475. Thus, no degradation was seen in the bulk conductivity of the sabot.

Chemistry of Black Residue from Launcher IIa

The elemental chemistry of the black residue, using EDAX, shows that the residue is made up mostly of aluminum (from the sabot) and copper (from the rails). Wavelength dispersive spectroscopy was used to detect the presence of light elements such as carbon and oxygen. However, no carbon or oxygen was detected in the residue. This means that the aluminum and copper remained in a metallic form, with perhaps a small amount of oxide present that was undetectable with WDS sensitivity.

An x-ray diffraction spectrum was obtained from the debris (fig. 10). Some of the peaks were identified as aluminum, aluminum oxide (from the insulating sidewalls in the launcher), and copper; however, many of the peaks could not be identified. This points to non-stoichiometric alloying of these elements which is caused by incomplete melting and mixing.

Microstructure of Black Residue and Debris

The microstructures of the larger chunks of debris from commissioning shots were analyzed. Figure 11 shows a 5 μ layer of black residue on a piece of the aluminum oxide insulating wall. Most of this black residue deposited on a piece of the aluminum oxide insulating wall in the form of submicron particles (fig. 12). However, there are also deposits of chromium-copper 30 μ wide that have landed on the wall in a molten

globular state (fig. 13). Due to melting and resolidification, the microstructure of this rail material has changed. Compare the original microstructure of the chromium-copper rails (fig. 14a) to the microstructure of the glob formed during commissioning (fig. 14b). In figure 14b, the chromium has come out of solution and migrated to the grain boundaries of the copper. It is unknown how hot the chromium-copper got or how fast it cooled in order to produce this microstructure. This change in the microstructure also points to changes in the physical properties of the chromium-copper such as hardness and conductivity. The original average hardness was 128 DPH, but the molten material has an average hardness of 70 DPH, which is very low. Since the conductivity of a material is usually inversely proportional to its hardness, it is likely that the conductivity has increased. No actual conductivity measurements could be made on the material since there was not enough to test.

CONCLUSIONS

1. The presence of water in the launcher caused high temperature oxidation on the contact surfaces of the sabot. High temperature oxidation caused the bubbles and cracks seen on the contact surfaces.
2. Extremely high temperatures caused the contact surfaces of the sabot to develop a microstructure similar to an electron beam welded structure.
3. Cracking at the roots and tips of the contact surfaces is caused by overheating and, subsequently, over-aging of the aluminum sabot. This results when certain elements, such as magnesium and silicon, diffuse out of the Al-7475 alloy and precipitate along the grain boundaries of the aluminum. Cracks initiate along the grain boundaries because they have been substantially weakened. Cracking in the root area is not caused by mechanical stresses and is not related to the fracture toughness of the material.
4. The black residue and debris from the commissioning shots are composed of non-stoichiometric compounds made of aluminum and copper. These compounds did not oxidize and may be thermally and electrically conductive.
5. The thickness of the black residue ranges from 5 to 30 μ . The residue deposited in the launcher in the form of submicron particles.
6. Globular pieces of chromium-copper found among the debris softened from 128 to 70 diamond pyramid hardness and had a different microstructure than the original rail material. Its conductivity has probably increased.

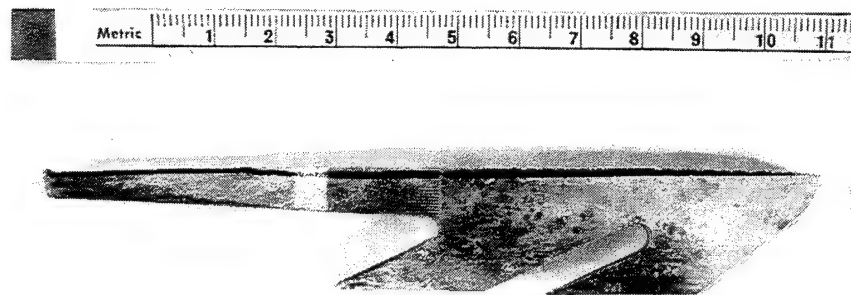


Figure 1
Sectioned sabot

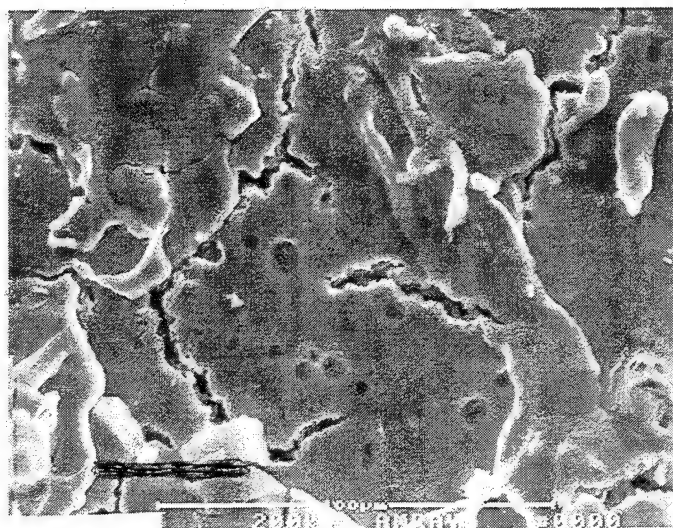


Figure 2
SEM of rear contact surface (540X)

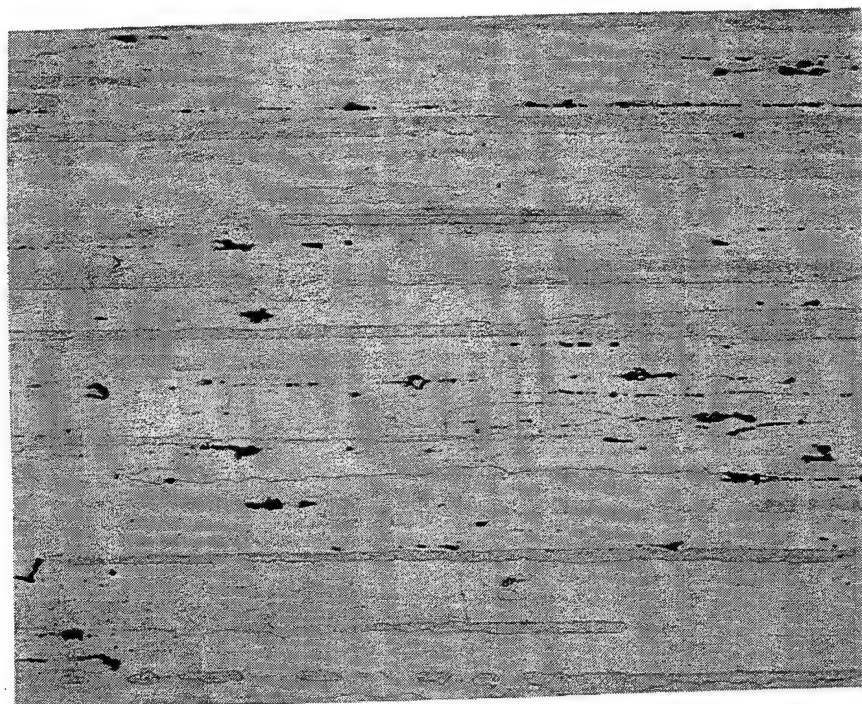


Figure 3
Microstructure of aluminum 7475 (200X)

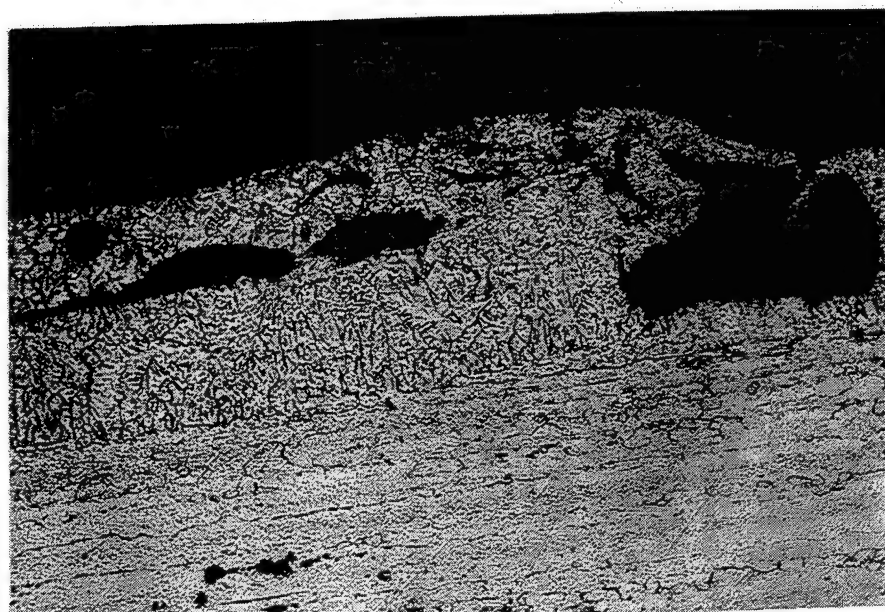


Figure 4
Microstructure of rear contact surface (500X)

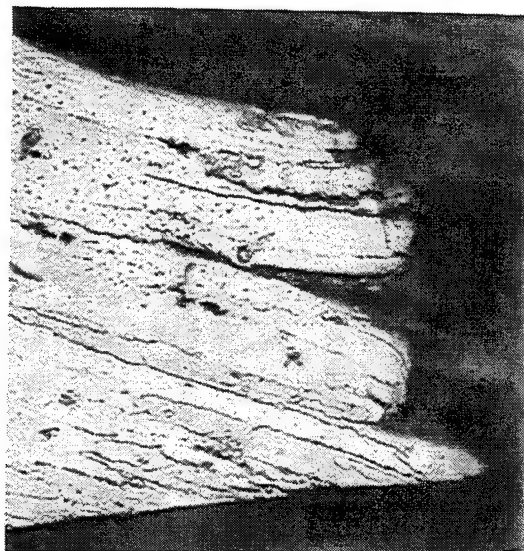


Figure 5
Microstructure of tip of rear contact surface (75X)



Figure 6
Microstructure of bottom-side of rear contact surface (500X)

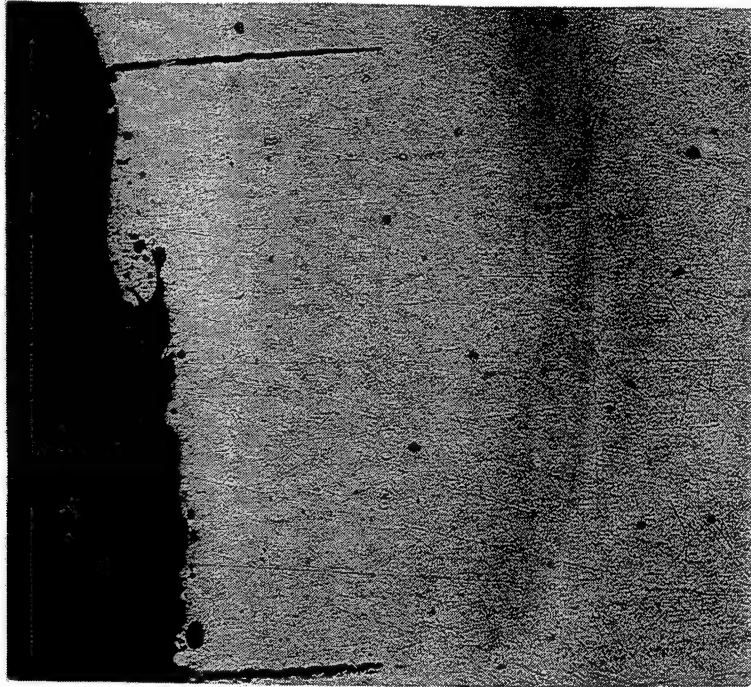


Figure 7
Crack formation at root(100X)

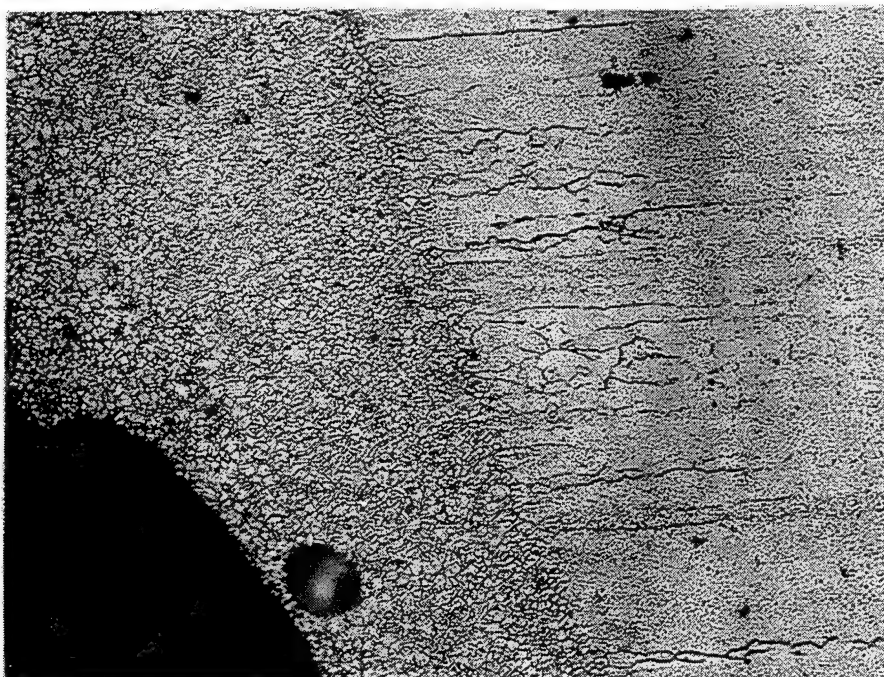


Figure 8
Microstructure of root (500X)

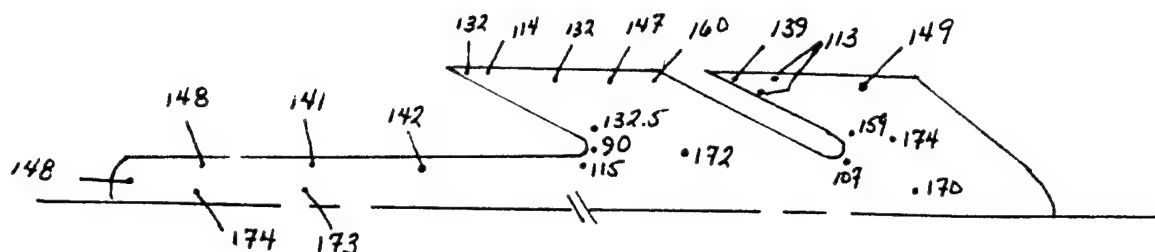


Figure 9
Hardness profile of sabot

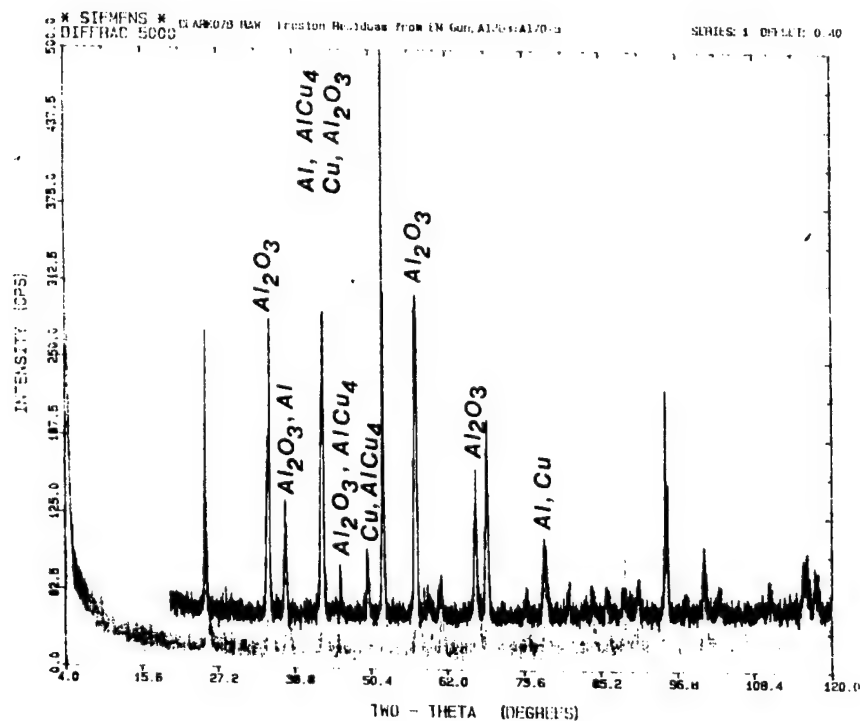


Figure 10
X-ray diffraction pattern of black residue

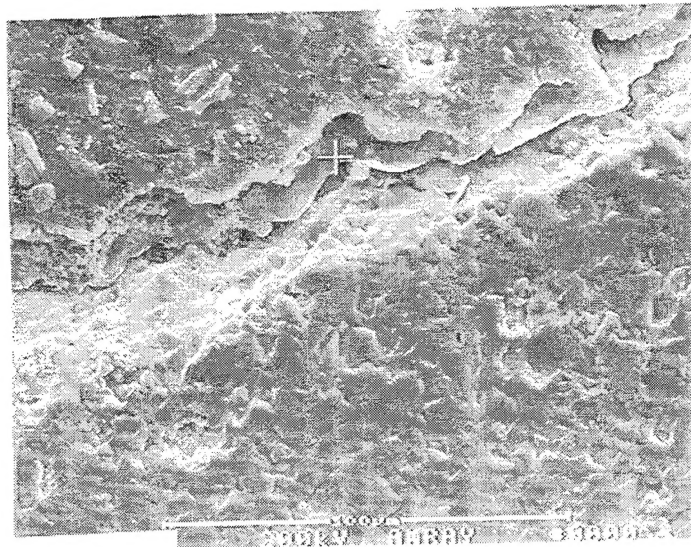


Figure 11
Layer of black residue on sidewalls (540X)

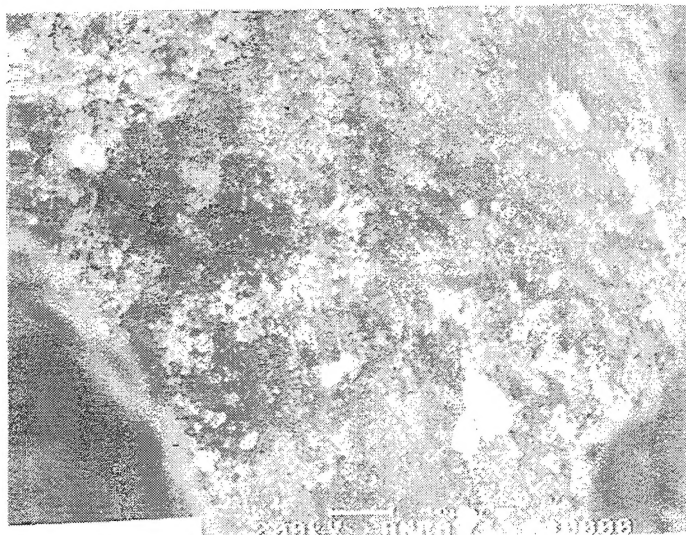


Figure 12
Black residue composed of submicron particles (825X)

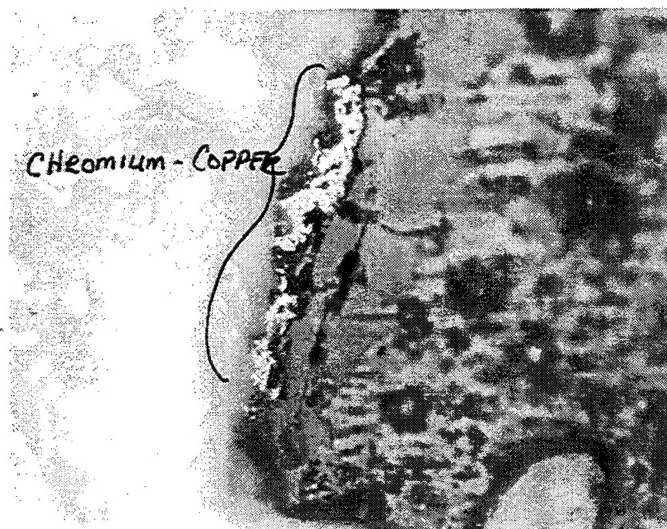
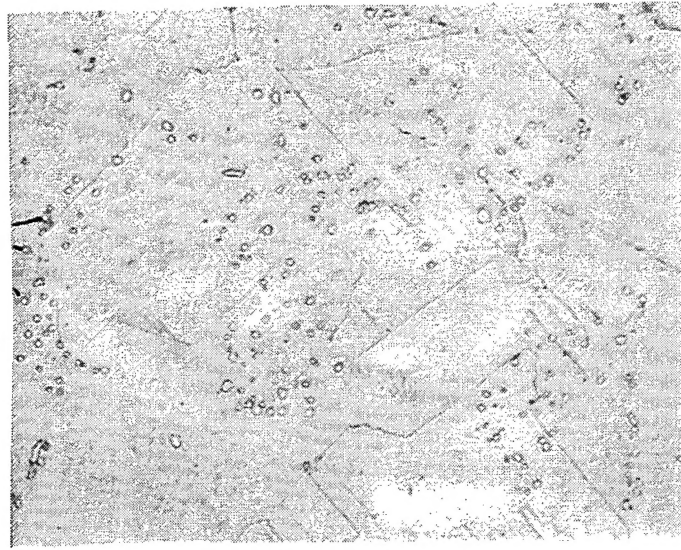
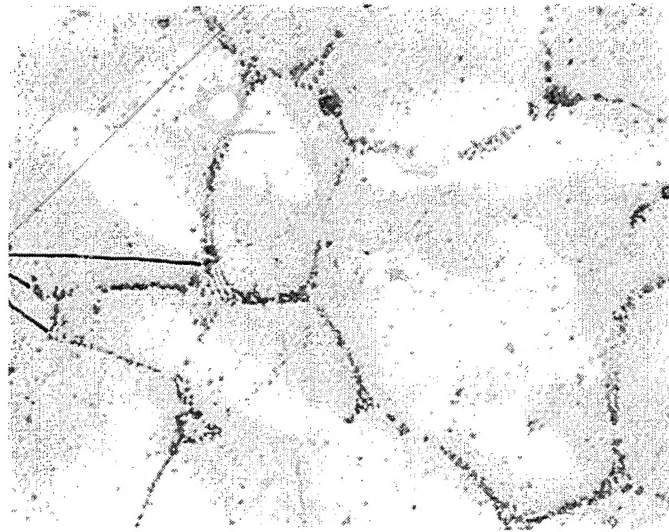


Figure 13
Chromium-copper deposit on sidewalls (300X)



(a) Original microstructure of the chromium-cooper rails (750X)



(b) Microstructure of the chromium-copper deposit (750X)

Figure 14
Microstructure of chromium-copper and chromium-copper deposit

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